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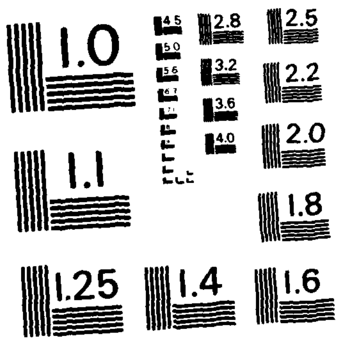

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Structures Technical Memorandum 406

ULTRASONIC TRANSIT TIME MEASUREMENTS USING FAST ANALOG TO DIGITAL CONVERSION AND A FAST FOURIER TRANSFORM BASED ALGORITHM

by

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SUMMARY

This paper describes the application of a fast (100MHz) analog to digital voltage converter and a discrete fast Fourier transform based algorithm to the determination of ultrasonic transit times. The precision obtained was typically better than 1 nanosecond.

Transit times over a range of frequencies (2-7MHz) have been measured using a broadband transducer excited by a chopped CW RF pulse. The frequencies chosen corresponded to those available from the discrete fast Fourier transform.

Documented listings of the programs used are provided.

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CONTENTS

1. INTRODUCTION

The potential of ultrasonic methods to determine residual stresses has been recognized by numerous workers (1,2,3). In recent years the availability of improved instrumentation has led to renewed effort (4,5) to develop practical techniques of ultrasonic determination of residual stress. The improved instrumentation includes, commercially available broadband shear wave transducers, EMAT'S (electromagnetic acoustic transducers), fast analog to digital voltage converters and associated microprocessor based hardware and software. The acquisition of digital records of the voltage response of the broadband transducer-sample system and subsequent computer processing enables the frequency dependence of ultrasonic transit times to be determined. The digital records will also help in the development of the theory of propagation of ultrasonic waves in stressed, textured materials, as they will enable a more detailed comparison of the theoretical and experimental results to be made. In this paper, details are given of the application of specific instrumentation and software to the determination of ultrasonic transit times at various frequencies.

2. EXPERIMENTAL

A block diagram of the experimental system used is shown in Figure 1. The transducer was a Panametrics type V157 5MHz broadband shear wave transducer with an active PZT element of 0.125 inch diameter. The transducer was excited with a chopped CW RF pulse generated by a HP3314A function generator. The transducer voltage response was amplified and then digitized at 10 nanosecond intervals by a Data Precision D6000 digital waveform analyzer with a Model 620 100MHz 8bit ±1.28V range plug-in. The Model 620 plug-in could acquire up to 30000 points with a 10 nanosecond interval between points, which corresponds to an elapsed time of 300 microseconds. Both the D6000 and HP3314A had remote computer control capability and were interfaced to a HP86 desktop computer via an IEEE-488 bus.

The D6000 has extensive programmable record handling and data manipulation capabilities. In particular, it was able to perform discrete fast Fourier transforms (DFFT) on any part of a digital record. The HP86 was used as the controlling computer on the IEEE-488 interface bus. The D6000 was initialized so as to be triggered by the transducer exciting pulse, and to take sufficient samples to encompass all return echoes with an adequate signal-to-noise ratio. Typically, for a 10mm thick 2024T4 aluminium alloy sample, the shear wave transit time was 6400 nanoseconds and, with the broadband transducer used the signal to noise ratio was falling rapidly past echo 4. An example of a digital voltage record for a 10mm path in 2024T4 aluminium alloy and at 4.69MHz is shown in Figure 2.

The ultrasonic transit time was obtained from the digital record by determining the corresponding points of the same phase (to within an integral multiple of 2Π) in the return echoes of interest. In the measurement of transit time, a precision of 0.1 to 1 nanoseconds was required to determine the stress level to 1MPa. The matching of corresponding points in different echoes is complicated by the frequency dispersion of the ultrasonic velocity and Papadakis (6) has noted that care needs to be taken to ensure that the transit time corresponding to the phase velocity and not the group velocity is measured.

In the system described here, the transit time was determined by initially selecting from the digital records the small regions within the record which contained the echoes. The number of sample points, and hence the time, of these regions, and the time at which these regions started were parameters in the main controlling program on the HP86. These parameters were subsequently sent by the HP86 to the D600 as part of the D6000's controlling program.

Using the terminology introduced by Allen et al (5), the time between these start points is referred to as the "coarse" transit time. A fine transit time adjustment was calculated by first performing a DFFT on the individual echo regions. The phase for the appropriate frequency calculated by the DFFT for each of the two echoes was subtracted, and, this difference, on multiplication by the angular frequency was the fine transit time. The transit time was then the sum of the coarse transit time and the fine transit time.

The DFFT required that the number of points be a power of two. Because of windowing effects the region was chosen so as to encompass the entire echo. This constraint, along with execution time constraints, put a limit on the number of RF cycles in the chopped CW RF pulse. For the frequency range possible (2-7MHz) and for a 256 point DFFT, 5 or 6 RF cycles could be used. As the time length of the DFFT record determined the frequency resolution, the choice of a 256 point DFFT with 10 nanosecond sampling time, constrained the frequencies that could be used to integral multiples of 0.391MHz.

3. DESCRIPTION OF COMPUTER PROGRAM

The main controlling program on the HP86 prompted the user to enter the following parameters: the length of the DFFT in sample points, the start points of all the regions within the record, and the number of records per frequency to be averaged. The program determined the appropriate integer for the start and finish frequency, given the DFFT length, and assuming 10 nanoseconds sampling time, from which the frequency

resolution could be calculated. It then initialized the HP3314A and initialized and programmed the D6000. When this was completed, the D6000 was requested to acquire a record and to run its program, which selects and performs DFFT's on the required regions. The HP86 waited for this program to finish, and then accessed the phase information for each echo at the appropriate frequency, and checked to see if it was valid. The phase differences were calculated and converted to fine transit times, which was followed by the updating of the running sums for the calculation of the average and standard deviation. The cycle of acquisition of data record, DFFT's by the D6000, transfer of phase data to HP86, and calculation of fine transit times for each echo pair was repeated the requested number of times for each frequency. The program concluded by printing all the relevant information. A documented listing of the HP86 program and the D6000 program is contained in Appendix 1.

4. RESULTS

The technique detailed above, has been used to investigate the frequency, temperature and stress dependence of the ultrasonic transit times in a extruded 10mm 2024T4 aluminium alloy sample. The results of these investigations are reported elsewhere (7). An example of the output of the program is given in Appendix 1. Examples of plots of the actual data in a region encompassing an echo and overplots of sinusodial curves of the phase calculated by the DFFT and with the frequency of the exciting pulse are shown in Figures 3,4, and 5.

5. DISCUSSION

The standard deviation of the mean of the transit time measurements have typically been below 1 nanosecond for echo 1 to 2 and echo 2 to 3. This precision allows determination of stresses to the order of 1MPa. However, for later echo pairs, the standard deviations can increase to above 1 nanosecond. At this stage the transit times are not corrected for diffraction effects (6,8), and any 2π errors (8) are corrected by hand. The effect of diffraction is to produce different transit times between echoes 1 and 2 to those between echoes 2 and 3 etc.. The diffraction corrections calculated by Allen show that the transit times between the early echoes are too short, but the correction quickly reduces to zero for later echo pairs. However, even after the addition of these corrections, Allen (8) has observed that the transit times between the various echo pairs are often different.

In the results obtained using the above technique, there was a significant variation in the transit times between the various echo pairs, which could not be explained by the diffraction effect calculated by Allen(8).

There are a number of other factors which could cause these transit time variations. These include, interference from shear to longitudinal mode-converted-waves, interference due to echoes from side walls, generation of incompletely linearly polarized shear waves by the transducer, complex interactions arising from the texture in the sample and the transducer/sample bond, and incomplete damping within the backing of the broadband transducer. The multiplicity and complexity of the possible factors involved, highlights the advantages of having a complete digital record of the transducer/sample system. This is because it will enable computer optimization of the various parameters of any theoretical model by comparison with the experimental determined digital records. Further experimental and theoretical study will be carried out to attempt to resolve the above problems. Currently experimental work is being performed with the aim of completely utilizing the broadband nature of the transducer. In this system, the transducer is excited by a very fast rise time pulse. The generated ultrasonic pulses have significant energy over a broad range (2-7MHz) of frequencies, and after Fourier analysis, the phase of the various frequency components can be determined. In this way, the transit times at a number of frequencies can be determined simultaneously. The results of this work will be reported in due course.

6. CONCLUSION

This work has demonstrated the potential of digital analysis techniques in the ultrasonic determination of residual stresses. The method described here has enabled ultrasonic transit times to be determined to a precision of typically 1 nanosecond over a range of frequencies. The transit time measurements obtained with this method have shown that further theoretical and experimental work is required before the effect of diffraction, mode conversion, texture and frequency, among others, are fully understood.

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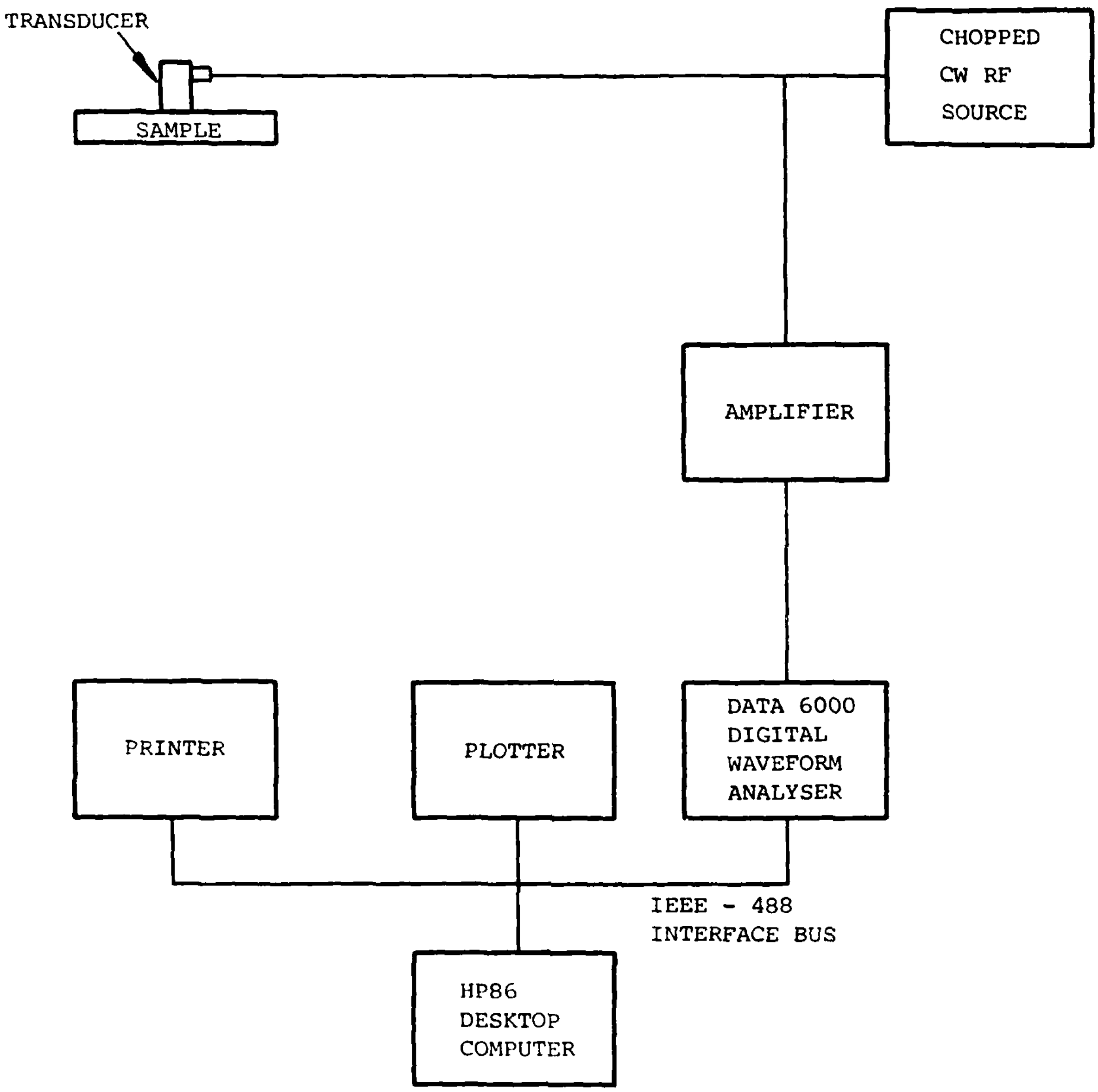

FIG. 1 BLOCK DIAGRAM OF EXPERIMENTAL ARRANGEMENT.

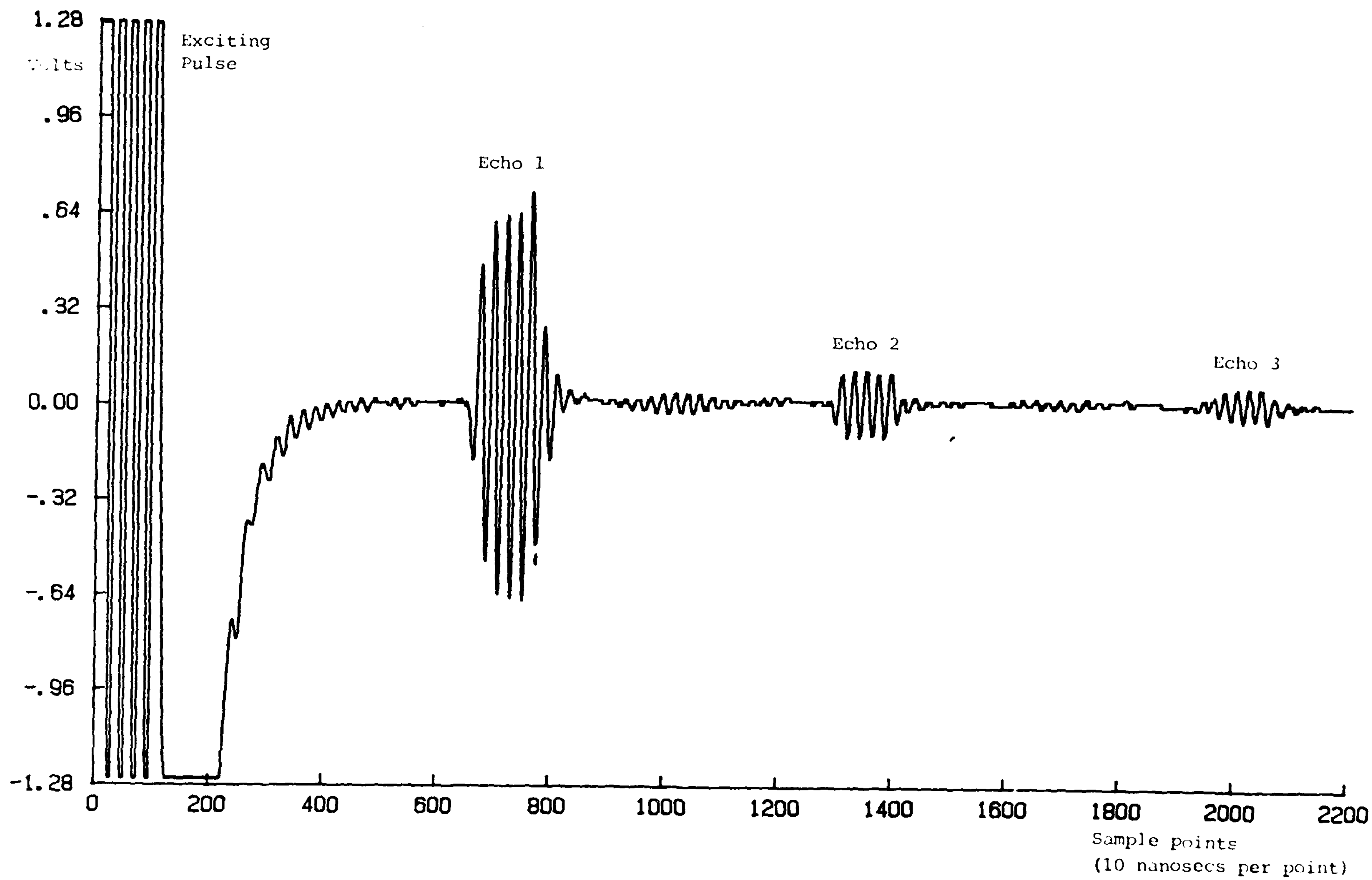

FIG. 2 D6000 DIGITAL VOLTAGE RECORD FOR A 10 MM PATH IN 2024T4 ALUMINIUM ALLOY. 4.69 MHz

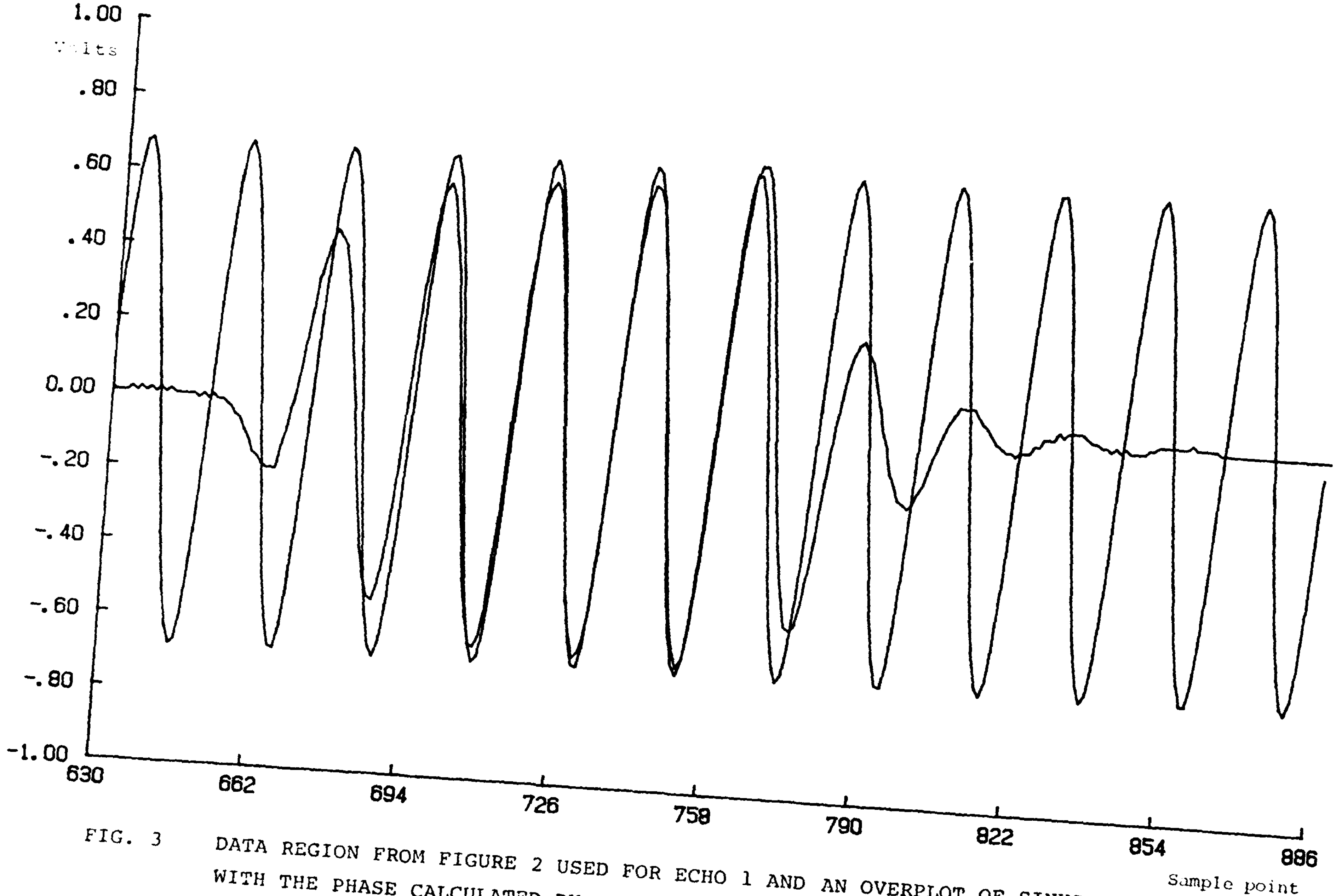

FIG. 3 DATA REGION FROM FIGURE 2 USED FOR ECHO 1 AND AN OVERPLOT OF SINUSOIDAL CURVE WITH THE PHASE CALCULATED BY THE DFFT.

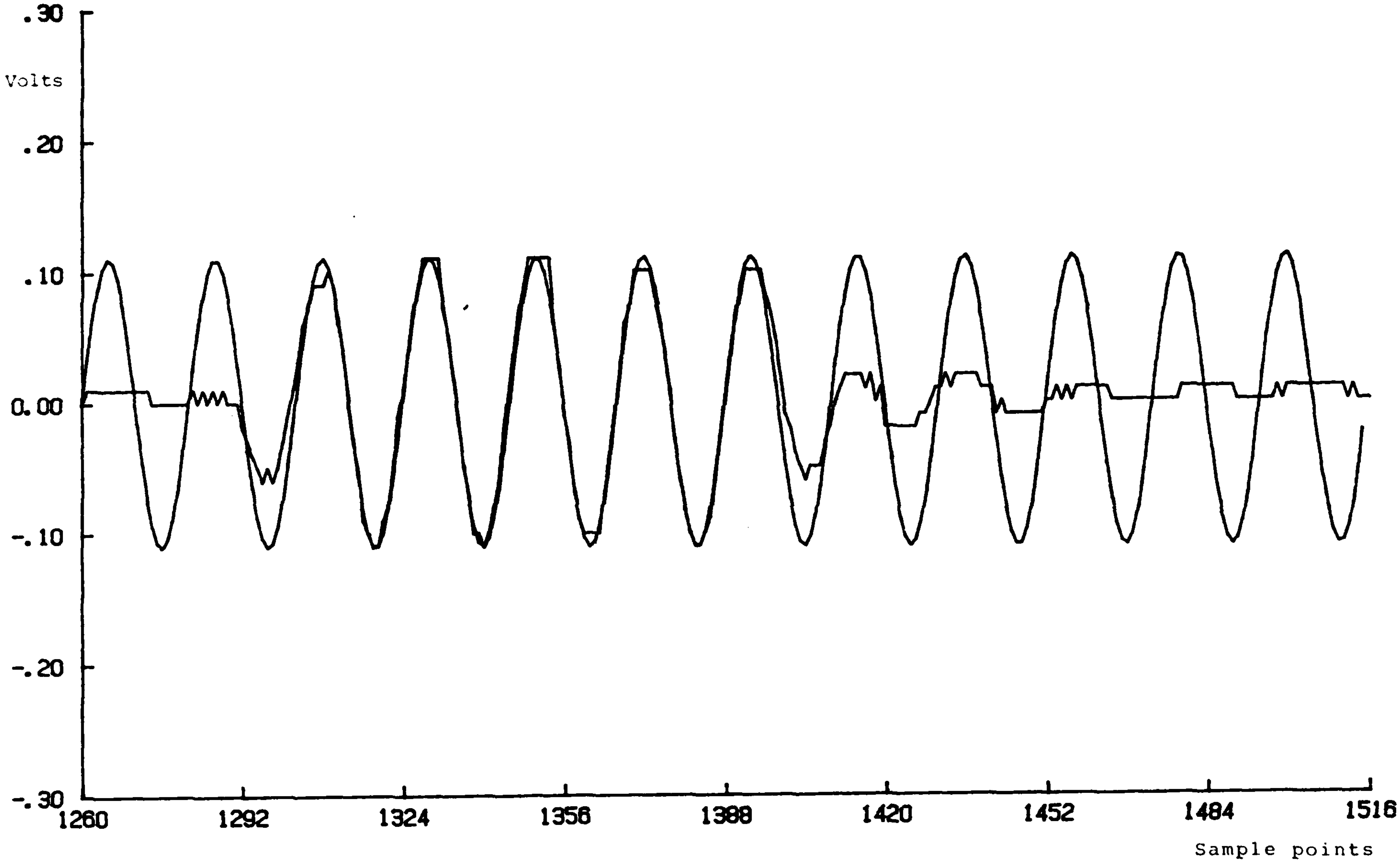

FIG. 4 DATA REGION FROM FIGURE 2 USED FOR ECHO 2 AND AN OVERPLOT OF SINUSOIDAL CURVE WITH THE PHASE CALCULATED BY THE DFFT.

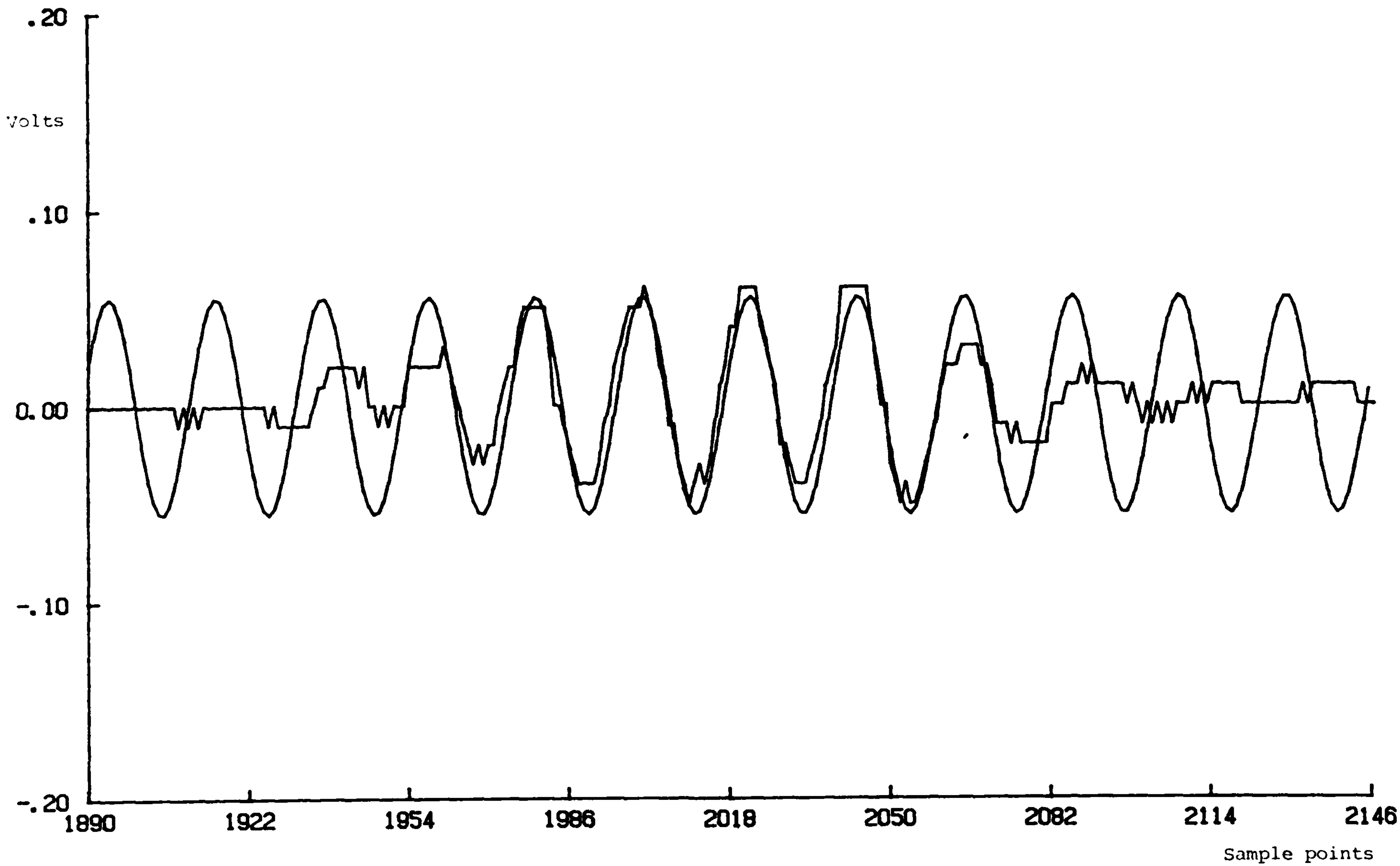

FIG. 5 DATA REGION FROM FIGURE 2 USED FOR ECHO 3 AND AN OVERPLOT OF SINUSOIDAL CURVE WITH THE PHASE CALCULATED BY THE DFFT.

APPENDIX 1

Listing of the main controlling program on the HP86, the program on the D6000 and typical output from the HP86 program. The output is for a 10mm transit path in 2024T4 aluminium alloy. Note that the transit times are not corrected for 2π errors. The date in the fourth column in the output are calculations of the standard error of the mean.

HP86 program name : TTIME.

```
10 DIM PH(5,20),FINETM(5,20),ES(5),DIFF(5),TIM(5)
20 REM  PH(I,J)      CONTAINS THE PHASE FOR ECHO I, RECORD J
30 REM  FINETT(I,J) CONTAINS THE FINE TRANSIT TIME BETWEEN ECHO I+1 AND
40 REM              ECHO I FOR RECORD J
50 REM  ES(I)        CONTAINS START IN DATA POINTS OF Ith ECHO REGIONS
60 REM               IN DATA RECORD ON D6000
70 REM  DIFF(I)      CONTAINS PHASE DIFFERENCE FOR ECHO PAIR I+1 AND I
80 REM  TIM(I)       CONTAINS TOTAL TRANSIT TIME FOR ECHO PAIR I+1 AND I
90 DIM DAT$[5],ANGLE$[5],TEMP$[5],STRESS$[6]
100 REM STRING VARIABLES USED TO STORE DATE, ANGLE OF TRANSDUCER,TEMPERATURE
110 REM  AND STRESS
120 STARTF=2.73 ! STARTING FREQUENCY IN MHz
130 ENDF=5.86 ! FINAL FREQUENCY IN MHz
140 DISP "ENTER LENGTH OF FFT (POWER OF TWO) "
150 INPUT LENGTH
160 DELF=100/LENGTH ! FREQ RESOLUTION IN MHz ASSUMING 10 NANOSECS
170 NST=FNRD(STARTF/DELF,0) ! LOCATION OF DATA FOR STARTF IN FFT OUTPUT
180 NEND=FNRD(ENDF/DELF,0) ! LOCATION OF DATA FOR ENDF IN FFT OUTPUT
190 DISP "INPUT NUMBER OF RECORDS PER FREQ FOR AVERAGING"
200 INPUT JMAX
210 ERRNUM=JMAX/2 ! NUMBER OF INVALID RECORDS ACCEPTED BEFORE USER IS
220 REM                PROMPTED
230 REM PROMPT FOR RUN INFORMATION
240 DISP "ENTER DATE , ANGLE AND TEMP,STRESS"
250 INPUT DAT$,ANGLE$,TEMP$,STRESS$
260 PRINT DAT$&" CALCULATION OF MEAN AND S.D OF FINE TRANSIT TIMES FOR";JMAX;" R
ECORDS"
270 PRINT "USING FUNCTION GENERATOR--ROTATION OF TRANSDUCER "&ANGLE$&" DEGREES"
280 PRINT "SAMPLE TEMPERATURE "&TEMP$&" DEGREES"
290 PRINT "STRESS ",STRESS$
300 PRINT @ PRINT "ECHO#","FREQ (MHz)","MEAN(NANOSECS)","STD DEV/(";JMAX;")^.5"
310 I=1
320 REM PROMPT FOR STARTING POINTS OF ECHO REGIONS WITHIN DATA RECORD
330 DISP "INPUT START OF ECHO#";I;" (-1 TO FINISH)"
340 INPUT ES(I)
350 IF ES(I)<> -1 THEN I=I+1 @ GOTO 330
360 NUMECHO=I-1 ! NUMBER OF ECHOES ENTERED
370 REM CHECK TO SEE IF D6000 REQUIRES INITIALIZATION AND PROGRAMMING
380 DISP "ENTER 1 IF DP6000 ALREADY SETUP"
390 INPUT SETFLAG
400 IF SETFLAG=1 THEN 610
410 NL=20
420 FOR I=1 TO NUMECHO
430 REM INITIALIZE DATA RECORDS ON D6000
440 CALL "MAKE" ( "ECHO"&VAL$ (I),LENGTH,0,.00000001,1,0,1,28,0 )
450 REM SEND PROGRAM TO D6000
460 REM SELECT ECHO REGIONS FROM DATA RECORD
470 CALL "SEND" ( VAL$ (I*NL)&" ECHO"&VAL$ (I)&"=BUF.A1("&VAL$ (ES(I))&","&VAL$
(ES(I)+255)&")" )
480 REM PERFORM DFFT ON ECHO REGION
490 CALL "SEND" ( VAL$ (I*NL+10)&" MAGS"&VAL$ (I)&"[PHAS"&VAL$ (I)&"]=FFT(ECHO"&
VAL$ (I)&",,6,0,0,12)" )
500 NEXT I
510 REM INITIALIZE HP3314A FUNCTION GENERATOR
520 OUTPUT 707 ;"RC5" ! RESTORES HP3314 TO STATE STORED IN MEMORY 5
530 REM                 !MODE= N CYCLE
540 REM                 !AMPLITUDE = 10.00 VOLTS
550 REM                 !NUMBER OF CYCLES = 5
560 REM                 !TRIGGER =INTERNAL
570 REM INITIALIZE D6000
580 CALL "SEND" ( "PROMPT=7;ERRM=7;TRGM=1;DARM;EXECON=1;" )
```

```
590 CALL "SEND" ( "DSPM=1;XOFF=6.0uS;TRGLEV=1.27V;NPTS(1)=4096;PERIOD(1)=10nS" )
600 REM LOOP FOR EACH FREQUENCY FROM NST TO NEND
610 FOR N=NST TO NEND
620 REM LOOP FOR EACH ECHO REGION
630 FOR I=1 TO NUMECHO
640 REM INITIALIZE VARIABLES USED FOR MEAN,STD. DEV. AND ERROR COUNTS
650 X(I)=0 @ X2(I)=0 @ ERRCNT(I)=0
660 NEXT I
670 FREQ=DELF*N ! CALCULATE ACTUAL FREQUENCY IN MHz
680 REM ROUND FREQ TO TWO DECIMAL PLACES
690 FREQ=INT (FREQ*100+.5)/100
700 REM SET FUNCTION GENERATOR TO REQUIRED FREQUENCY
710 OUTPUT 307 ;"FR="&VAL$ (FREQ)&"MZ"
720 REM LOOP FOR THE REQUIRED NUMBER OF RECORDS TO BE USED FOR AVERAGING
730 FOR J=0 TO JMAX-1
740 REM ACQUIRE DATA RECORD AND RUN PROGRAM ON D6000
750 CALL "SEND" ( "ARM" )
760 CALL "SEND" ( "DISARM" )
770 CALL "SEND" ( "RUN" )
780 REM LOOP TO SEE IF PROGRAM HAS FINISHED
790 CALL "GETVAL" ( "PGMST",PGMST )
800 IF PGMST=2 THEN 790
810 REM LOOP FOR EACH ECHO REGION
820 FOR I=1 TO NUMECHO
830 REM GET Nth POINT IN RECORD "PHAS", WHICH CONTAINS THE PHASE
840 CALL "SEND" ( "M=PHAS"&VAL$ (I)&"("&VAL$ (N)&")" )
850 CALL "GETVAL" ( "M",M )
860 IF M>0 THEN M=360-M @ GOTO 890
870 M=-M ! CONVERT TO POSITIVE DEGREES TO FIRST PEAK PAST T=0
880 REM STORE PHASE DATA
890 PH(I,J)=M
900 NEXT I
910 REM LOOP FOR EACH ECHO PAIR
920 FOR I=1 TO NUMECHO-1
930 REM COMPUTE DIFFERENCE IN PHASE
940 DIFF(I)=PH(I+1,J)-PH(I,J)
950 REM CHECK TO SEE IF RECORD WAS VALID
960 REM ONLY CHECK DIFFERENCE BETWEEN ECHO 1 AND ECHO 2
970 IF I>= 2 THEN 1180
980 REM STORE DIFFERENCE IF IT IS THE FIRST RECORD
990 IF J=0 THEN DIFFCK(I)=DIFF(I)
1000 REM ACCEPT RECORD IF VARIATION FROM FIRST RECORD DIFFERENCE IS < OR = 40
1010 IF ABS (DIFF(I)-DIFFCK(I))<= 40 THEN 1180
1020 REM ACCEPT RECORD IF AFTER A 2PI ADJUSTMENT, THE VARIATION FROM THE
1030 REM FIRST RECORD DIFFERENCE IS < OR = 20
1040 IF ABS (DIFF(I)+360-DIFFCK(I))<= 20 THEN PH(I+1,J)=PH(I+1,J)+360 @ DIFF(I)=
DIFF(I)+360 @ GOTO 1180
1050 IF ABS (DIFF(I)-360-DIFFCK(I))<= 20 THEN PH(I+1,J)=PH(I+1,J)-360 @ DIFF(I)=
DIFF(I)-360 @ GOTO 1180
1060 REM RECORD REJECTED INCREASE ERROR COUNT BY ONE
1070 ERRCNT(I)=ERRCNT(I)+1
1080 REM IF ERROR COUNT IS LESS THAN LIMIT THEN OBTAIN A NEW RECORD
1090 IF ERRCNT(I)<= ERRNUM THEN 750
1100 REM ERROR COUNT GREATER THAN LIMIT, INFORM USER
1110 DISP "MORE THAN ";ERRNUM;" RECORDS OUT OF ";J;" RECORDS HAVE HAD PHASE DIFF
S"
1120 DISP "GREATER THAN 10 DEGREES FROM THE INITIAL PHASE DIFF"
1130 DISP "BETWEEN ECHOES ";I;" AND ";I+1
1140 DISP "ENTER 2 TO STOP ,1 TO INCREASE ERROR CHECK#,0 TO GET NEW CHECK DIFF"
1150 INPUT TFLAG@ IF TFLAG=2 THEN STOP
1160 IF TFLAG=0 THEN 630
1170 DISP "ENTER NEW ERROR CHECK NUMBER" @ INPUT ERRNUM
1180 NEXT I
1190 REM UPDATE RUNNING SUMS OF PHASE DIFFS AND PHASE DIFFS SQUARED FOR
1200 REM ACCEPTED RECORDS
1210 FOR I=1 TO NUMECHO-1
```

```
1220 X(I)=X(I)+DIFF(I)
1230 X2(I)=X2(I)+DIFF(I)*DIFF(I)
1240 NEXT I
1250 REM
1260 NEXT J ! LOOP FOR NEXT RECORD
1270 REM
1280 REM CALCULATE MEAN AND STANDARD DEVIATION OF MEAN, AND CONVERT DEGREES
1290 REM TO NANOSECS
1300 FOR I=1 TO NUMECHO-1
1310 X(I)=X(I)/JMAX
1320 X(I)=X(I)/(.36*FREQ)
1330 X2(I)=X2(I)/(.1296*FREQ*FREQ)
1340 SD(I)=X2(I)-JMAX*X(I)*X(I)
1350 SD(I)=(SD(I)/(JMAX-1))^.5
1360 PRINT @ PRINT
1370 REM ROUND VALUES AND PRINT
1380 X=FNRD(X(I),1) @ S=FNRD(SD(I)/JMAX^.5,2)
1390 PRINT I;" AND ";I+1,FREQ,X,S
1400 FINETM(I,N)=X(I)
1410 NEXT I
1420 REM
1430 NEXT N ! LOOP FOR NEXT FREQUENCY
1440 REM
1450 REM PRINT FINAL RESULTS
1460 PRINT
1470 PRINT
1480 PRINT "OVERALL TRANSIT TIMES BETWEEN ECHOES AND DIFFERENCES"
1490 PRINT @ PRINT "ECHOES","FREQ//PERIOD(nS)","TRANSIT TIMES(nS)","DIFFERENCES"
1500 FOR N=NST TO NEND
1510 DELF=100/LENGTH
1520 FOR I=1 TO NUMECHO-1
1530 REM COMPUTE TRANSIT TIMES FOR EACH ECHO PAIR
1540 TIM(I)=(ES(I+1)-ES(I))*10+FINETM(I,N)
1550 NEXT I
1560 FOR I=1 TO NUMECHO-1
1570 FREQ=N*DELF
1580 S$=" "
1590 IF I<NUMECHO-1 THEN S$=VAL$ (FNRD(TIM(I+1)-TIM(I),1))
1600 PER=FNRD(1000/FREQ,1)
1610 REM ROUND AND PRINT
1620 FREQ=FNRD(FREQ,2) @ T=FNRD(TIM(I),1)
1630 PRINT I;"AND";I+1,FREQ,T
1640 PRINT " ",PER," ",S$
1650 NEXT I
1660 NEXT N
1670 REM PROMPT USER FOR NEW PARAMETERS IF REQUIRED
1680 DISP "ANOTHER RUN (1,0)"
1690 INPUT FLG
1700 IF FLG=0 THEN STOP
1710 DISP "ENTER NEW ANGLE,NEW TEMP,NEW STRESS"
1720 INPUT ANGLE$,TEMP$,STRESS$
1730 DISP "ADJUST PRINTER PRESS <CONT> TO CONTINUE"
1740 PAUSE
1750 GOTO 260
1760 STOP
1770 REM
1780 REM
1790 REM SUBROUTINE TO ROUND PARAMETER IN "VALUE" TO "PLACES" PLACES
1800 DEF FNRD(VALUE,PLACES)
1810 VALUE=INT (VALUE*10^PLACES+.5)/10^PLACES
1820 FNRD=VALUE
1830 FN END
1840 END
```

```
10 SUB "GETVAL" (NAME$.VALUE)
20 REM GETVAL OBTAINS THE VALUE OF THE PARAMETER ON THE D6000
30 REM WHOSE NAME IS CONTAINED IN THE STRING NAME$
40 OUTPUT 315 :NAME$
50 ENTER 315 : ANSWER$
60 ENTER 315 : B$
70 VALUE=VAL (ANSWER$)
80 SUBEXIT
90 SUBEND
```

```
10 SUB "MAKE" (NAME$,LENGTH,XOFFSET,XPERPNT,XUNIT,YOFFSET,YFSD,YUNIT)
20 REM CREATES A DATA RECORD ON THE D6000
30 REM CONSULT D6000 USERS MANUAL FOR EXPLANATION OF PARAMETERS
40 CALL "SEND" ( "PROMPT=3;ERRM=3" ) ! INITIALIZES PROMPT AND ERROR MODE
50 CALL "SEND" ( "TRCSRC(1)=BUF.A1" ) ! SETS TRACE ON SCREEN TO BUF.A1
60 OUTPUT 315 ;"NPTS(1)" ! PROMPTS D6000 TO SEND NUMBER OF POINTS
70 ENTER 315 : B$ ! IN DATA RECORD BUF.A1
80 LTH=VAL (B$) ! NUMBER STORED IN LTH
90 ENTER 315 : B$ ! RECEIVE PROMPT
100 CALL "SEND" ( "NPTS(1)="&VAL$ (LENGTH) ) ! ALTER LENGTH OF BUF.A1
110 XOFF=XOFFSET/(LENGTH*XPERPNT) ! CALCULATE VALUE TO BE SEND TO D6000 FOR
120 REM                            AN OFFSET OF XOFFSET
130 CALL "SEND" ( "TEMP1=BUF.A1" ) ! CREATE A TEMPORARY FILE THE SAME SIZE AS
140 REM                             BUF.A1
150 CALL "SEND" ( "TEMP1(0,"&VAL$ (LENGTH-1)&")=0.0" ) ! ZERO ALL VALUES
160 CALL "SEND" ( "TEMP2=UNIT(TEMP1,0,"&VAL$ (XOFF)&","&VAL$ (XPERPNT)&","&VAL$
(XUNIT)&")" )
170 REM  ALTER X OFFSET AND X UNITS PER POINT
180 CALL "SEND" ( NAME$&"=UNIT(TEMP2,1,"&VAL$ (YOFFSET)&","&VAL$ (YFSD)&","&VAL$
 (YUNIT)&")" )
190 REM RENAME RECORD AND ALTER Y OFFSET AND Y F.S.D
200 CALL "SEND" ( "DEL TEMP1;DEL TEMP2" )
210 REM REMOVE TEMPORARY FILES CREATED
220 CALL "SEND" ( "NPTS(1)="&VAL$ (LTH) )
230 REM RESTORE LENGTH OF BUF.A1
240 CALL "SEND" ( "LOCAL" )
250 REM RESTORE LOCAL CONTROL OF D6000
260 SUBEXIT
270 SUBEND
```

```
10 SUB "SEND" (A$)
20 REM SENDS STRING IN A$ TO D6000
30 REM SEND ASSUMES THAT D6000 HAS BEEN INITIALIZED TO SEND A ">"
40 REM PROMPT ON ACCEPTANCE OF MESSAGE
50 REM INITIALIZATION IS PERFORMED BY CALL "SEND" ("PROMPT=3")
60 DISP A$
70 REM DISPLAY STRING SENT ON HP86 SCREEN
80 OUTPUT 315 ;A$
90 REM 315 = DEFAULT ADDRESS OF D6000 ON IEEE-488 INTERFACE BUS
100 ENTER 315 : B$
110 IF B$[1]=">" THEN SUBEXIT
120 DISP B$
130 REM DISPLAYS ON HP86 SCREEN ANY MESSAGE SENT BY D6000 IN RESPONSE TO STRING
140 GOTO 100
150 SUBEND
```

```
10 ECHO1=BUF.A1(630,885)
20 MAGS1[PHAS1]=FFT(ECHO1,,6,0,0,12)
30 ECHO2=BUF.A1(1260,1515)
40 MAGS2[PHAS2]=FFT(ECHO2,,6,0,0,12)
50 ECHO3=BUF.A1(1890,2145)
60 MAGS3[PHAS3]=FFT(ECHO3,,6,0,0,12)
```

6/2 CALCULATION OF MEAN AND S.D OF FINE TRANSIT TIMES FOR 10 RECORDS

USING FUNCTION GENERATOR--ROTATION OF TRANSDUCER 0 DEGREES
SAMPLE TEMPERATURE 23 DEGREES
STRESS 0

ECHO#	FREQ (MHz)	MEAN(NANOSECS)	STD DEV/(10)^.5
1 AND 2	2.73	35.9	.09
2 AND 3	2.73	102.7	.36
1 AND 2	3.13	39.9	.1
2 AND 3	3.13	89.1	.53
1 AND 2	3.52	38.8	.07
2 AND 3	3.52	-189.4	.27
1 AND 2	3.91	42	.13
2 AND 3	3.91	-152.4	.28
1 AND 2	4.3	-204.4	.17
2 AND 3	4.3	140.7	.26
1 AND 2	4.69	9	.08
2 AND 3	4.69	175.1	.19
1 AND 2	5.08	.5	.14

2 AND 3	5.08	-13.4	.17
1 AND 2	5.47	6.2	.14
2 AND 3	5.47	-.9	.17
1 AND 2	5.86	11.8	.14
2 AND 3	5.86	13.9	.25

OVERALL TRANSIT TIMES BETWEEN ECHOES AND DIFFERENCES

ECHOES	FREQ//PERIOD(nS)	TRANSIT TIMES(nS)	DIFFERENCES
1 AND 2	2.73 365.7	6335.9	66.8
2 AND 3	2.73 365.7	6402.7	
1 AND 2	3.13 320	6339.9	49.2
2 AND 3	3.13 320	6389.1	
1 AND 2	3.52 284.4	6338.8	-228.2
2 AND 3	3.52 284.4	6110.6	
1 AND 2	3.91 256	6342	-194.4
2 AND 3	3.91 256	6147.6	
1 AND 2	4.3 232.7	6095.6	345.1
2 AND 3	4.3 232.7	6440.7	
1 AND 2	4.69 213.3	6309	166.1
2 AND 3	4.69 213.3	6475.1	
1 AND 2	5.08 196.9	6300.5	-17.9

2 AND 3	5.08 196.9	6286.6	
1 AND 2	5.47 182.9	6306.2	-7.2
2 AND 3	5.47 182.9	6299.1	
1 AND 2	5.86 170.7	6311.8	2.1
2 AND 3	5.86 170.7	6313.9	

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16. Abstract

This paper describes the application of a fast (100MHz) analog to digital voltage converter and a discrete fast Fourier transform based algorithm to the determination of ultrasonic transit times. The precision obtained was typically better than 1 nanosecond.

Transit times over a range of frequencies (2-7MHz) have been measured using a broadband transducer excited by a chopped CW RF pulse. The frequencies chosen corresponded to those available from the discrete fast Fourier transform.

Documented listings of the programs used are provided.

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